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GROWTH OF *OCTOLASMIS COR* (AURIVILLIUS, 1892) ON THE GILLS OF *SCYLLA SERRATA* (FORSKAL, 1755)

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Abstract

A unique experimental procedure to determine the growth of *Octolasmis cor* used to advantage the suspended crab cage operation in the Straits of Johore, Singapore. This allowed growth measurements of a previously inaccessible symbiotic organism in a natural situation. The resulting data suggest that growth to sexual maturity is rapid, occurring within a two-week period. It is speculated that this is an adaptation to an ephemeral substrate which allows *O. cor* to maximize its reproductive capacity by increasing egg production and the number of potential hosts.

Introduction

Although there are well-documented reports on the growth of certain species of Balanomorpha (Barnes and Powell, 1953; Costlow and Bookout, 1953; Mawatari *et al.*, 1954; Barnes, 1956; and Daniel, 1958), there are relatively few such reports on the Lepadomorpha (Evans, 1958; Skerman, 1958; Page, 1983), and none on epizoic barnacles such as *Octolasmis* which live attached to certain Crustacea. *Scylla serrata* (Forskal, 1755) was the host selected for this study because in earlier work (Jeffries *et al.*, 1982), all of the 45 individuals examined had *Octolasmis* in their gill chambers.

S. serrata is indigenous to the Johore Straits (Chuang, 1961), an estuary fed by several rivers and rich in plankton flora and fauna (Khoo, 1967; Tham *et al.*, 1970). Large numbers are also imported to Singapore by air from nearby Southeast Asian countries and held in cages suspended in the Johore Straits until ready for market. The purposes of this research was to measure the growth rate of *Octolasmis cor* from cyprid to large adult on the gills of *S. serrata* under nearly natural conditions and to consider the implications for coevolution of the epizoite and its host.

Materials and Methods

Methods of managing the hosts are essential prerequisites for the study of growth in epizoic organisms. Clean substrates must be provided for attachment of epizoites, the time of attachment must be known or at least inferable, and the hosts must be maintained under natural or nearly natural conditions. The crab cage operation in the Straits of Johore provided a unique opportunity to meet these conditions. In turn, this allowed the development of techniques to determine the rate of growth of a species of *Octolasmis* which, because they occur within the gill chambers of decapods, are inaccessible to direct observation and sequential measurement.

From late May until the middle of August 1983, *S. serrata* were obtained within 48 hours of arrival in Singapore by air freight from Indonesia. Crabs 83 mm to 115

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mm in carapace width and within five days of ecdysis ("pre-molts") were selected for the experiment. They were recognized by a marked color contrast between the white ventral thorax (sternum) and the dark blue abdomen; and by a distinctive condition most noticeable on the underside of the postero-lateral carapace (pterygostomian), in which the old exoskeleton is thin and brittle and yields to pressure, and the epimeral suture begins to separate.

Each pre-molt crab was assigned a number and placed alone in a wire cage (30 cm × 17 cm × 14 cm) with mesh size of 14 mm by 20 mm. The cage was suspended mid-way between the surface and the bottom in the Johore Straits about 300 m north of the terminus of Lim Chu Kang Road. The overall depth at the experiment site was about 10 m at mean high water. On an annual basis the salinity ranges from 28.00 to 30.10‰, and sea surface temperatures range from 28.4 to 30.8°C (Khoo, 1966). Each crab was checked every 24 hours until it molted. By designating the molt time to be mid-way between the observed molt and the previous inspection, it was possible to insure that the designated time was within 12 hours of the actual molt. The exuviae was removed from the cage, the crab was maintained in its cage at mid-water for 24 hours, then lowered to the bottom for the remainder of the experiment. Crabs were maintained at the bottom for various periods of time as substrates for growing *Octolasmis cor. O. cor* cyprids occur in the plankton in the Johore Straits and are commonly found on hosts exposed for more than 24 hours. The shortest interval from molting to the time the crab was sacrificed was 36 hours. At 24-hour increments additional crabs were sacrificed up to a maximum of 372 hours (15.5 days).

Results

Of 70 *S. serrata* processed during the experiment, 66 were observed to host *Octolasmis*. The crabs were sacrificed, their gills removed and preserved in 10% neutral formalin. Later 837 metamorphosed *O. cor* were located, counted, and measured as described previously (Jeffries and Voris, 1983).

The intervals over which the crabs were exposed to infestation by *O. cor* are arranged into periods of 48 hours in Table I and the largest *O. cor* observed for each period is given. For purposes of this study individual barnacles of large size, not averages, were used to calculate growth rates since they could be assumed to be among the earliest to attach to the recently molted crabs. Calculation of their growth rates, made over the full exposure time, thus yields the most conservative estimates.

The largest barnacle (4.719 mm capitular length) among the 837 observed, was

Table I

The number and maximum capitular length of O. cor *obtained from the gills of* S. serrata *which had been exposed 36–360 hours post-ecdysis*

Hours	Number of crabs	Number of cyprids	Number metamorphosed	Largest capitular length (mm)
0–48	5	106	2	1.00
60–108	14	314	122	1.86
120–168	13	103	221	2.57
180–228	12	30	220	4.00
240–288	10	12	132	3.72
300–348	8	10	113	4.72
360–	4	19	27	3.58
	66	594	837	

taken from a crab held in the Straits of Johore for 312 hours (13 days) following ecdysis (Table I). It can be inferred that this is near the maximum size for *O. cor* based on an examination of 190 barnacles from a series of pre-molt crabs and exuviae, which yielded a maximum capitular length of 4.576 mm (Table II). Based on carapace widths of 82.75 mm to 106.65 mm, these pre-molt crabs and exuviae corresponded to instars 15, 16, and 17, and were at least 50, 57, and 77 days respectively from the preceding instar (Ong, 1966; Hill, 1975). Clearly, near maximum barnacle size can be attained within a relatively short period of time (13 days) and the additional time between 13 and 50, 57, or 77 days does not result in much additional growth of *O. cor*. Thus, the two-week period which follows crab ecdysis is ideal for growth rate determinations. To estimate the rate of growth during this period, two methods were employed.

The first estimate utilized the large *O. cor* samples (122 and 113 adults) retrieved from 14 and 8 crabs exposed for 60–108 hours and 300–348 hours, respectively (Table I). These exposure periods are near the ends of the range. For the 60–108 hour period, the maximum capitular length observed was 1.859 mm, and for the 300–348 hour period it was 4.719 mm. Dividing the difference between the two capitular lengths (2.860 mm) by the difference in the exposure time of the two crabs hosting these barnacles (312 − 108 = 204 hours) yielded a growth rate estimate of 0.014 mm per hour, or 0.336 mm per day. This could be an underestimate of the growth rate if the barnacles did not attach very soon after the crab was placed in the Johore Straits, but not a significant overestimate unless the 4.719 mm barnacle is decidedly atypical. Although this does not appear to be the case, based on the survey of pre-molt crabs and exuviae listed in Table II, a second method of estimating growth rate minimizes the possibility of this type of error.

Two additional pieces of information needed for the second growth estimate calculation were obtained by examining the size distribution of all the metamorphosed barnacles within each exposure period. First this examination revealed that the smallest metamorphosed barnacle measured 0.572 mm. Second, it allowed determination of the probable length of the period between cyprid settlement and the conclusion of

TABLE II

The number and maximum capitular length of metamorphosed O. cor *obtained from gill pair number five of* S. serrata *pre-molt crabs and exuviae*

	Octolasmis cor	
	Number	Length (mm)
Pre-molt crabs		
1	52	3.575
2	2	3.861
3	6	4.004
4	22	3.575
5	29	3.146
	111	
Exuviae		
1	16	3.146
2	7	4.576
3	23	2.717
4	10	3.575
5	23	3.575
	79	

metamorphosis (and thus the base point in time at which the growth phase begins) as follows.

Two barnacles measuring 1.001 mm and 0.715 mm were found on two different crabs exposed 48 hours after ecdysis. No other metamorphosed barnacles were found within the gill chambers of the five crabs exposed 36–48 hours. Based on the minimum observed size of a metamorphosed barnacle, 0.572 mm, it appears that the 1.001 mm barnacle had already grown 0.429 mm following its metamorphosis. From the above growth rate estimate of 0.014 mm per hour, the 0.429 mm represents as much as 30.6 hours of growth. Thus the 1.001-mm barnacle found on the 48-hour crab may have metamorphosed as early as 17.4 hours (48–30.6) after attachment. However the paucity of metamorphosed barnacles (2) in the presence of numerous cyprids (106) in this exposure group of crabs argues that it would be more conservative, and realistic, to use 24 hours as the minimum time until metamorphosis and the beginning of the growth phase.

A second measure of growth was made by subtracting the minimum capitular length at metamorphosis (0.572 mm), from the capitular length of the barnacle whose growth rate was being estimated. This figure was divided by the number of hours the host crab was exposed minus 24 hours that allowed for cyprid attachment, metamorphosis, and onset of growth, to give the growth rate in mm per hour. The latter figure was rounded to three significant digits and multiplied by 24 to yield a mm per day growth rate. Table III presents these growth rate estimates for the three largest barnacles in each of the exposure intervals represented by at least five crabs.

Overall these growth rates ranged from 0.264 to 0.480 mm per day. Growth rates of the largest, second largest, and third largest barnacles ranged from 0.336 to 0.480 mm per day, 0.264 to 0.360 mm per day, and 0.264 to 0.408 mm per day, respectively. The amount of overlap among these estimates indicates that the growth rates of the largest barnacle in each interval were not substantially faster than the rates of the second and third largest barnacles. The growth rate of 0.336 mm per day calculated

TABLE III

Growth rate estimates for the three largest barnacles for each crab exposure interval represented by more than five crab hosts

Interval hours	Barnacle size (mm)	Hours of exposure	Growth rate mm/day
60–108	1.859	108	0.360
	1.716	108	0.336
	1.430	84	0.336
120–168	2.574	168	0.336
	2.145	156	0.288
	2.145	144	0.312
180–288	4.004	192	0.480
	3.289	204	0.360
	3.289	180	0.408
240–288	3.718	240	0.360
	3.718	288	0.264
	3.575	240	0.336
300–348	4.719	312	0.336
	3.718	312	0.264
	3.718	312	0.264

for the very largest barnacle in the study (4.719 mm) was not atypical. The mean, median, and mode of the 15 growth rate estimates are all 0.336 mm per day. In addition, the first method of calculating growth rate (comparing the largest barnacles of the 60–108 hour and 300–348 hour intervals) also resulted in an estimate of 0.336 mm per day.

Discussion

The fastest growth rate, 0.480 mm per day, was attained by the largest barnacle in the 180–228 hour exposure interval (the second largest barnacle in the growth rate study overall). This rate is very close to the 0.5 mm per day reported for *Lepas hillii* Leach (Evans, 1958), growing under natural conditions on the side of a ship for one- and two-month periods at 24.2–26.1°C.

Our estimates support the contention that growth of *O. cor* is rapid, roughly a third to a half mm per day. For the largest barnacle (4.719 mm), 0.336 mm per day represents a daily growth increment of about 7% of its final capitular length.

The striking similarities among the growth estimates suggest that the techniques developed in this study allowed us to measure growth more precisely than was previously possible. Furthermore it appears that growth occurred under nearly optimal conditions. Freshly molted crabs provided a clean, uncrowded substrate, and the rich plankton flora and fauna of the Straits provided what was probably unlimited food for the barnacles. In a previous study (Jeffries *et al.*, 1982), 10 *Scylla serrata* were observed to host 1324 *O. cor* (an average of 132.4 per crab), plus 1337 individuals of another *Octolasmis* species, for a total average of 266.1 barnacles per crab. In this study the average number of metamorphosed *O. cor* per crab was 11.9; adding in the average number of individuals of other species, the total average number of individual barnacles on each crab was 24.5.

The estimate made in this study of the time between attachment of the *O. cor* cyprid larvae until metamorphosis, 24 hours at temperatures of 28.4–30.8°C, compares favorably with the reported time of 20 to 72 hours at 24–29°C for *O. mulleri* reared in the laboratory (Lang, 1976). Another genus of barnacle, *Balanus amphitrite variegatus,* required only 37 minutes for cyprid attachment through metamorphosis, at an unspecified temperature in the laboratory (Daniel, 1958).

In contrast to the high incidence of gravid individuals among the *O. cor* collected from pre-molt crabs and exuviae, not one of the 837 *O. cor* examined in this growth study was gravid, although many were sexually mature. This suggests several interesting possibilities regarding the growth strategy of *O. cor,* which we can now begin to explore.

Attainment of sexual maturity by *O. cor* within two weeks on a host crab which spends 50–77 days between molts has a significant advantage: it allows for increased egg production, through the increased numbers of egg clutches that are possible over a greater period of time. In addition, previous work on a related barnacle, *O. mulleri,* on the blue crab *Callinectes sapidus,* demonstrated a strong positive correlation between capitular size and brood size (Jeffries and Voris, 1983).

A second advantage of rapid growth and attainment of sexual maturity, is that the number of available hosts is effectively increased: The ninth instar of *Scylla serrata* is a minimum of 15 days from the previous instar according to Ong (1966). Thus the compression of *O. cor* growth to sexual maturity into a short period of about two weeks allows it to utilize smaller (and more numerous) hosts, thereby enabling it to further increase its usable substrate.

We suspect that the barnacles are attuned, perhaps hormonally, to the physiological state of the crabs, allowing them to direct their resources toward growth during the two weeks immediately following crab ecdysis.

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LITERATURE CITED

BARNES, H. 1956. The growth rate of *Chthamalus stellatus* (Poli). *J. Mar. Biol. Assoc. U. K.* **35:** 355–61.

BARNES, H., AND H. T. POWELL. 1953. The growth of *Balanus balanoides* (L.) and *Balanus crenatus* Brug. under varying conditions of submersion. *J. Mar. Biol. Assoc. U. K.* **32:** 107–28.

CHUANG, S. H. 1961. *On Malayan shores, Singapore,* MUWU SHOSA.

COSTLOW, J. D., JR., AND C. G. BOOKOUT. 1953. Moulting and growth in *Balanus improvisus. Biol. Bull.* **105:** 420–33.

DANIEL, A. 1958. The development and metamorphosis of three species of sessile barnacles. *J. Madras. Univ. Sect. B.* **XXVIII** (1): 23–47.

EVANS, F. 1958. Growth and maturity of the barnacles *Lepas hillii* and *Lepas anatifera. Nature* **182**(4644): 1245–1246.

HILL, B. J. 1975. Abundance, breeding and growth of the crab *Scylla serrata* in two South African estuaries. *Mar. Biol.* **32:** 119–126.

JEFFRIES, W. B., H. K. VORIS, AND C. M. YANG. 1982. Diversity and distribution of the pedunculate barnacle *Octolasmis* in the seas adjacent to Singapore. *J. Crustacean Biol.* **2**(4): 562–569.

JEFFRIES, W. B., AND H. K. VORIS. 1983. The distribution, size, and reproduction of the pedunculate barnacle, *Octolasmis mulleri* (Coker, 1902), on the blue crab, *Callinectes sapidus* (Rathbun, 1896). *Fieldiana Zool. N. S.* **16:** 1–10.

KHOO, H. W. 1966. A preliminary study of the physical, chemical and biological characteristics of Johore Straits. M.Sc. Thesis. University of Singapore.

LANG, W. H. 1976. The larval development and metamorphosis of the pedunculate barnacle *Octolasmis mulleri* (Coker, 1902) reared in the laboratory. *Biol. Bull.* **150:** 255–267.

MAWATARI, S., Y. HIROSSAKI, AND S. KOBAYASHI. 1954. Settlement and growth of acorn barnacle, *Balanus amphitrite communis* Darwin, II. *Misc. Rep. Res. Inst. Nat. Resour. (Tokyo)* **34:** 48–57.

ONG, KAH SIN. 1966. Observations on the post-larval life history of *Scylla serrata* Forskal, reared in the laboratory. *Malays. Agric. J.* **45**(4): 429–443.

PAGE, H. M. 1983. Effect of water temperature and food on energy allocation in the stalked barnacle, *Pollicipes polymerus* Sowerby. *J. Exp. Mar. Biol. Ecol.* **69:** 189–202.

SKERMAN, T. M. 1958. Rates of growth in two species of *Lepas (Cirripedia). N. Z. J. Sci.* **1:** 402–411.

THAM, A. K., C. M. TO, M. Y. GAN, C. S. TAN, H. T. FOO, AND J. L. GAN. 1970. The distribution of plankton in Singapore Straits for the period from April 1968 to March 1969. *Proc. 2nd. CSK Symp.,* Tokyo.